SOIL ORGANIC MATTER MANAGEMENT FOR SUSTAINABLE CASSAVA PRODUCTION IN VIETNAM

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ABSTRACT

Soil nutrient depletion and exhaustion can be prevented by application of adequate amounts of chemical fertilizers, organic manures or compost, or by incorporation of cassava plant tops, green manures, intercrop residues or prunings of hedgerows.

Farm-yard manure (FYM) is an essential source of nutrients to improve soil fertility and increase growth and yields of crops grown in upland areas. Application of FYM can increase available P, exchangeable K, mineralizable N and soil organic matter (OM).

Intercropping cassava with grain legumes and returning their residues to the soil is a profitable technology which also improves soil fertility. Planting contour hedgerows of green manure crops can significantly reduce soil losses and run-off on sloping lands. The nutrient balance in the soil under cassava cropping is normally negative, especially with respect to K. Returning the residues of intercropped grain legumes could alleviate this problem. A combination of FYM, inorganic fertilizers, and incorporation of residues of leguminous crops often increases yields significantly. This is an easily adoptable technology. Farmers have successfully participated in research and the transfer of this technology to other farmers in the community.

It has been estimated that cassava takes up 99-153 kg N, 57-113 kg P_2O_5, 38-56 kg K_2O, 50-81 kg Ca and 19-32 kg Mg/ha. These amounts could be removed from the soil. Where cassava was intercropped with leguminous crops and the crop residues were returned, about 49-80 kg N, 34-57 kg P_2O_5, 12-18 kg K_2O, 24-39 kg Ca and 9-15 kg Mg/ha were returned to the soil.

Alley cropping cassava with contour hedgerows of *Tephrosia candida* is a well-established practice in some parts of north and central Vietnam. *Tephrosia* hedgerows produced an average of 0.5-1.0 t/ha/year of dry biomass for incorporation into the soil. This may contribute 10-20 kg N/ha. In intercropping systems, black bean could supply about 1.5-2.0 t/ha of dry residues containing 35-40 kg N/ha, or peanut could supply about 4-5 t/ha of dry residues with 50-70 kg N/ha. By intercropping grain legumes with cassava and returning the residues, in three years the soil OM had increased by 0.22% in the surface and 0.19% in the subsoil, as compared to the control treatment. Returning the bean residues and applying FYM increased the soil OM and N; soil OM was increased by 0.28-0.61% in the surface soil and increased by 0.25-0.82% in the subsoil. Planting *Tephrosia candida* as contour hedgerows and returning pruned leaves and stems to the soil, soil OM was increased by 0.3-0.4%, compared to the previous two years.

Soil organic matter plays an essential role in soil fertility. Soil OM management by the use of FYM, green manures, intercropping and green hedgerows, and returning crop residues to the soil, is a technology widely applied by farmers for achieving sustainable agriculture in Vietnam.

INTRODUCTION

Of the total land area of 33 million ha in Vietnam, 75% is hilly or mountainous. About 21% of the total land area, or 6.9 million ha, is used for agriculture, of which 5.3 million ha for annual crops, while 42%, or 13.8 million ha, has been abandoned or is left in fallow. Thai Phien and Nguyen Tu Siem (1996) stated that “as a direct consequence of planting upland rice and cassava for food self sufficiency, more than one million ha have become eroded skeleton soils with no value for agriculture or for forestry”. Similarly, ISRIC (1997) reports that of the 38.6 million ha of total land area in Vietnam, 8.6 million

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ha (22%) are suffering from various degrees of water erosion, and 5.0 million ha (13%) from fertility decline.

In Vietnam, cassava (*Manihot esculenta* Crantz) is the fifth most important food crop in terms of area planted, after rice, maize, vegetables and sweet potato. In 1998 cassava was harvested in 238,700 ha, with a production of 1.98 million tonnes of fresh roots and a yield of 8.3 t/ha.

Howeler (1992) estimated that 66% of cassava in Vietnam is grown on Ultisols, 17% on Inceptisols, 7% on Oxisols, 4% on Alfisols and the remaining 6% on Entisols and Vertisols. Most of the Ultisols and Inceptisols are characterized by a light texture, acid pH and low levels of organic matter (OM) and nutrients. According to a farm-level survey conducted in 1990/91 of over 1,100 households in 45 districts of all cassava growing regions of Vietnam (Pham Van Bien *et al*., 1996), 59% of cassava is grown on sandy soils, 3.9% on silty soils, 11.7% on clayey soils and 25.3% on rocky soils. About 45% of cassava is grown on sloping land.

Extensive farming and shifting cultivation are common practices in upland areas. Cutting forests for agricultural production results in increased soil erosion and degradation of soil fertility. Upland soils have more constraints for crop growth. Low organic matter, soil acidity and low levels of nutrients are found in large areas. Previous research indicate that soil organic matter had a positive relationship with crop yield, especially in the uplands (Thai Phien and Luong Duc Loan, 1994; Huynh Duc Nhan *et al*. 1995; Thai Phien *et al*., 1995; Le Sinh Sinh et al., 1998). Building up the soil organic matter improves soil fertility, and crop yields could significantly increase.

This paper deals mainly with the aspect of organic matter management and erosion control on sloping lands with the objective of increasing yields and/or income for the farmer.

1. Soil Fertility Changes as a Result of Cassava Production in Vietnam

1.1. Soil Nutrient Depletion Under Cassava With No Soil Protection

Growing cassava and other annual crops on sloping lands may cause serious soil loss by erosion. **Table 1** shows the amount of soil loss by erosion under different cropping systems in upland areas. Land under secondary forest covered 80-90% of the soil surface, and annual soil loss was relatively low. With cassava cultivation, the soil loss was highest (98.6 t/ha/year). Differences in soil loss between different cropping systems was related to the degree of soil cover. More soil cover reduces the impact of rain drops falling directly on the soil.

Water erosion removed a layer of 12.3 mm of soil/year in areas of cassava cultivation, while in a tea plantation a layer of 2.6 mm was lost. Soil covered by natural grass lost a layer of 1.0 mm (**Table 2**). At the same time, nutrients in the sediments were also lost by water. Cassava cultivation resulted in the greatest nutrient loss from the soil. The loss of N, P and K was least from land under natural grass.

Table 1. Land cover and soil loss under different cropping systems.

Cropping	Soil cover (%)	Soil loss (t/ha)
1. Secondary forest	80-90	12.4
2. Maize	30-50	14.7
3. Upland rice	10-15	95.1
4. Cassava	10-15	98.6

Source*: *Luong Duc Loan, 1997.

Table 2. Soil and nutrient loss as affected by different cropping systems.

	Soil layer eroded	Soil loss by erosion		Nutrients lost with soil loss (kg/ha)		
	(mm)	(t/ha)	(%)	N	P_2O_5	K_2O
Monoculture cassava	12.3	145.1	100	145.1	110.0	31.3
Tea plantation	2.6	33.3	23	22.9	16.6	7.3
Natural grass	1.0	12.0	8	9.6	4.8	2.6

Source: *Nguyen Dinh Kiem, 1989.*

Nutrient losses from land under natural grass, averaged 10 kg N, 5 kg P_2O_5 and 3 kg K_2O/ha/year. Cassava cultivation without good soil management could result in a nutrient loss that is 14 times higher for N, 22 times for P, and 10 times for K as compared to that of land under natural grass.

Extensive cassava cultivation caused a reduction in soil organic matter (OM) content. Soil humus became depleted in both quantity and quality. The total soil OM and humic acid were reduced, so the Ch/Cf ratio was reduced (**Table 3**).

Table 3. The effect of continuous cassava cultivation on various soil organic matter compounds.

Length of cassava cultivation	OM (%)	AH	AF	Ch/Cf	Compound (R_2O_3)
1 year	1.72	0.48	0.64	0.75	0.45
6 years	0.80	0.21	0.33	0.64	0.17
10 years	0.55	0.09	0.36	0.17	0.08

Source: *Nguyen Tu Siem and Thai Phien, 1993.*

Long-term cassava cultivation resulted in a loss of bases such as Ca and Mg which in turn increased soil acidity. After six years of continuous cassava cultivation, the soil OM was reduced to about 50% and the Ch/Cf ratio had decreased from 0.75 to 0.64. After 10 years, this ratio was as low as 0.17 while the soil OM was only 1/3 of the initial amount.

Results of soil chemical analyses under forest and under cassava plantations are presented in **Table 4**. It is clear that after 1-2 years of cassava cultivation without adequate inputs of fertilizer and without erosion control, resulted in soil nutrient depletion. Soil pH dropped about 0.1-0.4 units and the soil OM dropped to 59-72% of its initial value.

1.2. Erosion as a Result of Cassava Cultivation

Cassava is oftentimes blamed for causing severe erosion when grown on slopes. There is no doubt that cassava cultivation, like that of all annual food crops, causes more run-off and erosion than leaving the land in forest, in natural pastures or under perennial trees (**Table 5**). This is mainly due to the frequent loosening of soil during land preparation and weeding, as well as due to the lack of canopy and soil cover during the early stages of crop development. The question is whether cultivation of cassava results in more or less soil loss than that of other annual crops.

Table 4. Chemical properties of a ferralsol derived from basaltic rock, under forest and under one or two years of cassava.

Cropping system	Soil depth. (cm)	pH in KCl	Total contents (%)			Exch. cations (me/100 soil)	
			OM	N	P_2O_5	Ca++	Mg++
Forestry	0-20	4.2	5.80	0.26	0.25	2.00	0.80
	20-40	4.1	3.30	0.11	0.10	1.18	0.40
	40-60	4.4	3.01	0.10	0.09	1.60	0.76
Cassava 1 year	0-20	3.8	4.18	0.08	0.11	1.46	1.20
	20-40	4.1	2.19	0.11	0.21	1.40	0.40
	40-60	4.3	1.08	0.10	0.11	1.20	1.60
Cassava 2 years	0-20	3.8	3.40	0.14	0.24	0.12	0.04
	20-40	3.8	2.08	0.06	0.20	0.04	0.04

Source: *Nguyen Tu Siem and Thai Phien, 1993.*

Table 5. Amount of soil erosion on sloping land, as influenced by different land use systems in Vietnam.

Land use system	Eroded soil (t/ha/year)	Eroded soil (%)
Cassava (monoculture)	145.1	100
Tea (10 years old)	33.3	23
Planted pine forest	28.7	20
Natural grass	12.0	8

Source: *Nguyen Dinh Kiem, 1989.*

Compared with other crops cassava establishes a canopy cover only slowly, often requiring 3-4 months to reach full canopy cover (Nguyen Tu Siem and Thai Phien, 1993). Moreover, the cassava canopy cover is effective only in protecting the soil from rainfall-induced erosion, but is not effective in reducing runoff-induced erosion, which occurs near the soil surface, and which becomes increasingly important as the slope increases (Rose and Yu, 1998). This may lead to increased erosion. On the other hand, cassava does not need intensive land preparation and a smooth seed bed like many seeded crops, nor does it require more than one land preparation per year, compared with 2-3 times for short-cycle crops like most grain legumes, maize and sorghum. Moreover, once the canopy is established there is no more need for weeding, while the canopy is effective in reducing raindrop impact, and thus erosion.

When soil particles are dislodged by the impact of raindrops or by the scouring action of overland flow, and move down-slope with runoff, the field not only loses the most fertile part of the soil, i.e. the topsoil, but also associated organic matter, manures, fertilizers and beneficial micro-organisms, such as mycorhizal fungi. Moreover, clay particles, once dislodged are quickly carried down slope, resulting in a preferential loss of clay and a lightening of soil texture. This may be the reason why soils used for a long time for cassava cultivation were found to be much lower in clay, organic C and CEC than those used for forest, rubber or cashew (**Table 6**).

Table 6. Chemical properties of various horizons of a Haplic Acrisols that have been under different land use in southeastern Vietnam.

Criteries	Forest	Rubber	Sugarcane	Cashew	Cassava	CV (%)
Organic C (%)	1.032a	0.839ab	0.796ab	0.579ab	0.496b	44.7
Total N (%)	0.058a	0.054ab	0.040abc	0.032bc	0.022c	36.7
Available P, Bray 2 (ppm)						
-1st horizon	5.21b	20.90a	20.68a	4.85b	15.33ab	37.5
-2nd horizon	2.48b	7.03a	7.92a	3.19b	5.31ab	32.6
-3rd horizon	1.57b	2.83ab	3.82a	1.08ab	3.82a	44.6
CEC (me/100g)	3.43a	2.94a	3.24a	2.39ab	1.53b	27.1
Exch. K (me/100g)						
-1st horizon	0.132a	0.127a	0.051b	0.070ab	0.060b	66.3
-2nd horizon	0.073a	0.046ab	0.022b	0.031ab	0.021b	75.1
Exch. Mg (me/100g)	0.145a	0.157a`	0.055ab	0.046ab	0.036b	89.1

Values are average of 6-10 profiles per cropping system. Within rows data followed by the same letter are not significantly different at 5% level by Tukey's Studentized Range Test.
Source: *Cong Doan Sat and Deturck, 1998.*

2. Soil Fertility Improvement by Organic Manure

2.1. The Effect of Organic Fertilizer Application on Crop Yields

2.1.1 Effect of farm-yard manure application

When the soil organic matter is low, the application of manures is an effective technology to improve the soil in upland areas. Intercropping leguminous crops with cassava and returning the residues to the soil can increase crop yields (**Table 7**).

In the cassava-black bean or peanut intercropping systems, the application of FYM increased the bean yield between 33.3 and 88.9%, and the peanut yields between 26.7 and 48.5%, compared to the control treatment without FYM application.

In the treatment with *Tephrosia candida* hedgerows, the bean and peanut yields were reduced in the first three years. After that, the peanut yield was similar to that of the control treatment. It indicates that the intercropping of *Tephrosia candida* initially reduced the cultivated area resulting in a reduction of bean yields as compared with the control treatment. After three years, soil fertility had improved by incorporating the leaves of *Tephrosia candida* as well as by reducing soil erosion.

Table 7. Yield of leguminous intercrops in cassava as affected by FYM application.

Treatments[1)]	Black bean yield (t/ha)	Peanut yield (t/ha)			
	1992	1993	1994	1995	Average
1. NPK	0.09	0.98	0.92	1.14	1.01
2. NPK + 3 t/ha FYM	0.12	1.16	1.17	1.52	1.28
3. NPK + 6 t/ha FYM	0.17	1.35	1.33	1.83	1.50
4. NPK + 12 t/ha FYM	0.14	1.40	1.26	1.63	1.43
5. NPK + *Tephrosia hedgerows*	0.07	0.93	0.93	1.19	1.02
LSD at 0.05	0.08	0.14	0.07	0.28	

[1)] NPK = 60 kg N + 60 P_2O_5 + 120 K_2O/ha
Source: *Thai Phien et al., 1996.*

After four years of intercropping, the average yield of intercropped peanut with hedgerows of *Tephrosia* was similar to that of the control treatment without hedgerows while the cassava yield with application of manure increased 14-32% as compared to the control treatment without manure (**Table 8**). Growing *Tephrosia candida* hedgerows and returning the residues to the soil could improve soil fertility, resulting in higher yields of cassava and intercropped legumes as compared to the control treatment without hedgerows.

Table 8. Effect of the application of various amounts of FYM on cassava yields from 1992 to 1995. Hoa Son commune, Luong Son distict, Hoa Binh province

Treatments[1)]	Cassava fresh root yield (t/ha)				
	1992	1993	1994	1995	Average
1. NPK	12.7	15.0	12.5	13.2	13.4
2. NPK + 3 t/ha FYM	15.0	16.9	13.6	15.6	15.3
3. NPK + 6 t/ha FYM	16.8	19.0	14.2	16.3	16.6
4. NPK + 12 t/ha FYM	18.3	18.3	16.8	17.3	17.7
5. NPK + *Tephrosia hedgerows*	11.2	14.0	18.3	19.5	15.8
LSD at 0.5	3.4	2.98	1.97	1.22	

[1)] NPK = 60 kg N + 60 P_2O_5 + 120 K_2O/ha
Source: *Thai Phien et al., 1996.*

2.1.2. The effect of organic fertilizer application on soil properties

As mentioned above, upland soils are mainly poor in organic matter and total nitrogen. Application of farm-yard manure (FYM) can improve soil organic matter (OM) and nitrogen in the soil. The effect of FYM on the soil OM and nitrogen in the soil is presented in **Table 9**. Bean residues were returned to the soil during three years of cassava-bean intercropping. The OM content was increased by 0.22% in the surface- and 0.19% in the sub-soil as compared to the control treatment. Returning the bean residues combined with FYM, increased the soil OM and nitrogen. The OM content was increased by 0.28-0.61% in the surface soil and increased by 0.25-0.82% in the subsoil. In treatment 4, intercropping *Tephrosia candida* as hedgerows and returning crop residues to the soil, soil OM was increased by 0.3-0.4%, compared to the past two years.

Table 9. Effect of FYM application on soil organic matter (SOM) and N contents in the surface soil (0-15 cm) in a cassava-bean intercropping experiment conducted in Hoa Son commune, Luong Son district, Hoa Binh province from 1992 to 1994.

Treatments[1)]	SOM (%)			N (%)		
	1992	1994	Δ	1992	1994	Δ
1. NPK	2.36	2.58	0.22	0.161	0.179	0.018
2. NPK + 3 t/ha FYM	2.21	2.68	0.47	0.148	0.156	0.008
3. NPK + 6 t/ha FYM	2.40	2.68	0.28	0.148	0.190	0.042
4. NPK + 12 t/ha FYM	1.69	2.30	0.61	0.143	0.174	0.030
5. NPK + *Teph. candida* hedgerows	1.69	2.01	0.32	0.136	0.179	0.043

[1)] NPK = 25 kg N + 50 P_2O_5 + 50 K_2O/ha
Source: *Nguyen Cong Vinh et al., 1998.*

Total nitrogen in the soil increased by application of animal manures. After two years the N content had increased 0.042% in the treatment with 6 t FYM/ha and 0.030% with 12 t FYM/ha. Hedgerows of *Tephrosia candida* increased the N content 0.043%.

Application of organic manures can also change the content of mineralizable N in the soil. Soil organic N need to be mineralized before being absorbed by the plant (**Table 10**). Mineral nitrogen in the soil was analyzed at room temperature (T_0) and after incubation at 40ºC for 1 week (T_1). The difference in extracted N between T_0 and T_1 indicates the mineralizable N in the soil. Mineralizable N increased by manure application. Differences between T_0 and T_1 ranged from 15.6 µg/g in the control treatment to 20.9-27.5 µg/g soil in treatments with FYM.

Table 10. Effect of application of various levels of FYM on mineralizable N in the soil after one week of incubation at 40ºC.

Treatments[1)]	Mineralizable N (µg/g soil)		
	T_0	T_1	T_0-T_1
1. NPK	10.5	26.1	15.6
2. NPK + 3 t/ha FYM	14.4	36.6	22.2
3. NPK + 6 t/ha FYM	18.3	39.2	20.9
4. NPK + 12 t/ha FYM	18.3	45.8	27.5
5. NPK + *Teph. candida* hedgerows	15.7	31.4	15.7
LSD	1.79	3.62	

[1)] NPK = 25 kg N + 50 P_2O_5 + 50 K_2O/ha
Source: *Nguyen Cong Vinh et al., 1998.*

Table 11 shows the effect of organic manure application on soil fertility improvement. Available P and K in the soil increased by the application of NPK, and by FYM and green manures from beans intercropped or by hedgerows. In the treatment with hedgerows of *Tephrosia candida*, available P increased most, from 2.8 ppm P in the first year to 9.94 ppm P in the 3rd year. Available P and K in the soil increased with increasing rates of FYM application.

2.2. Effect of the Combined Application of Organic Manure and Inorganic Fertilizer and Lime in Cassava Beans/Peanut Intercropping Systems.

Combining intercropping cassava with grain legumes and fertilization is an effective way to improve soil fertility. Crop residues were returned to the soil to build up soil organic mater. **Table 12** shows that crop yields in the cassava-beans system increased with the rate of N, P and K combined with lime. When N, P and K were combined with FYM, crop yields were higher than that combined with lime. This indicates that FYM is more effective in increasing the yields of both crops in the cassava-bean system. Crop yields were highest with the combined application of N, P, K, FYM and lime.

This combined application increased cassava yields from 11 to 19 t/ha, black bean yields from 78 to 162 kg/ha and peanut yields from 546 to 870 kg/ha.

Table 11. Available phosphate and potassium in the soil as effected by the application of organic manures in a cassava-bean intercropping experiment conducted in Hoa Son commune, Luong Son district, Hoa Binh province from 1992 to 1994.

Treatments[1)]	P (ppm)			K (mg/100g)		
	1992	1994	Δ	1992	1994	Δ
1. NPK (control)	4.21	7.00	2.79	2.35	3.12	0.77
2. NPK.+3 t/ha FYM						
3. NPK +6 t/ha FYM	4.20	7.65	3.45	2.73	5.85	3.12
4. NPK +12 t/ha FYM	4.69	9.59	4.90	1.95	6.63	4.48
5. NPK + Cont.+*Teph. candida* hedgerows	2.80	9.94	7.14	2.35	4.68	2.33

[1)] NPK = 25 kg N + 50 P_2O_5 + 50 K_2O/ha
Source: *Nguyen Cong Vinh et al., 1998.*

Table 12. Effect of the application of chemical fertilizers, FYM and lime on the yields of crops in a cassava-bean/peanut intercropping experiment conducted in Hoa Son commune, Luong Son district, Hoa Binh province from 1992 to 1994.

Treatments[1)]	Cassava root yield (Mean 1992-94)		Intercropped bean yields			
			Black bean (1992)		Peanut (Mean 1993-94)	
	t/ha	%	kg/ha	%	kg/ha	%
1. FYM	11.5	100	78	100	546	100
2. NPK low input+lime	14.4	125	96	123	730	132
3. NPK low input+FYM	16.8	146	129	166	836	156
4. NPK high input+lime	14.8	128	104	134	731	140
5. NPK high input+FYM	16.5	143	143	155	788	145
6. NPK high input+FYM+lime	18.8	163	162	208	870	158
LSD	0.27		56.2		126.8	

[1)] FYM = 3 t/ha; lime = 500 kg/ha; NPK low input = 25 kg N, 50 P_2O_5, 50 K_2O/ha;
NPK high input = 50 kg N, 100 P_2O_5, 100 K_2O/ha
Source: *Thai Phien and Nguyen Cong Vinh, 1998.*

2.2.1. The effect of balanced fertilization

Plant nutrients are usually lost from the soil by plant uptake and removal, soil erosion and leaching. The removal of nutrients with a cassava crop was calculated to be 62-153 kg N, 83-181 kg P_2O_5 and 67-147 kg K_2O/ha. This is one cause of the negative nutrient balance in cassava cultivation.

To overcome this problem, fertilization, intercropping and returning crop residues to the soil are useful solutions. However, previous research showed that the application of 30-60 kg N, 30-60 kg P_2O_5, and 50-100 kg K_2O/ha still did not compensate for the losses (**Table 13**). When cassava was intercropped with grain legumes, the amount of 49-80 kg N, 33.8-56.8 kg P_2O_5, and 12.1-18.2 K_2O/ha were returned with leguminous residues (**Table 14**).

Table 13. Effect of the application of various levels of N, P and K on the nutrient balance (kg/ha/year) in a cassava monocropping system in Hoa Son commune, Luong Son district, Hoa Binh province, 1992-1994.

NPK applied	N			P_2O_5			K_2O		
	NA[1)]	NR[2)]	NB[3)]	NA[1)]	NR[2)]	NB[3)]	NA[1)]	NR[2)]	NB[3)]
$N_0P_0K_0$	0	62	-62	0	82.7	-82.7	0	66.7	-66.7
$N_1P_0K_1$	30	108	-78	0	123.4	-123.4	50	102.4	-52.4
$N_1P_1K_0$	30	76	-46	30	111.8	-81.8	0	87.0	-87.0
$N_1P_1K_2$	30	135	-105	30	88.4	-50.4	100	87.8	+12.2
$N_1P_1K_1$	30	125	-95	30	144.2	-114.2	50	116.9	-66.9
$N_0P_1K_1$	0	120	-120	30	140.3	-110.3	50	113.3	-63.3
$N_2P_1K_1$	60	134	-74	30	163.8	-133.8	50	132.5	-82.5
$N_1P_2K_1$	30	138	-108	60	158.5	-98.5	50	130.2	-80.2
$N_2P_2K_2$	60	153	-93	60	180.8	-120.8	100	146.9	-46.9

[1)] NA = nutrients applied by fertilizers; [2)] NR= nutrients removed by crop; [3)] NB = nutrient balance

Source: *Nguyen Cong Vinh and Thai Phien, 1997.*

Table 14. Effect of fertilization on the nutrient balance (kg/ha/year) in the cassava-peanut intercropping system in Hoa Son commune, Luong Son district, Hoa Binh province, 1992-1994.

Treatment		Stems	N	P_2O_5	K_2O	Ca	Mg
1. FYM	RM*	-	99	57.1	37.5	50	19
	RT**	3,910	49	33.8	12.1	24	9
2. NPK low input+lime	RM*	-	118	84.6	43.6	64	24
	RT**	4,050	60	42.3	14.5	29	11
3. NPK low input+FYM	RM*	-	121	90.2	47.2	63	26
	RT**	4,220	64	45.1	15.7	32	12
4. NPK high input+lime	RM*	-	135	98.7	49.6	71	28
	RT**	4,450	76	50.8	16.9	36	14
5. NPK high input+FYM	RM*	-	136	98.7	54.5	76	29
	RT**	4,910	79	56.4	18.2	38	15
6. NPK high input+FYM+lime	RM*	-	153	112.8	55.7	81	32
	RT**	5,070	80	56.8	18.2	39	15

Note: RM*Removal, RT** returned to the soil; “Stems” are peanut residues.

Plants take up nutrients from the soil for plant growth and yield. Those nutrients can be removed or returned to the soil. The amounts taken up were estimated at 99-153 kg N, 57-113 kg P_2O_5, 38-56 kg K_2O/ha, 50-81 kg Ca and 19-32 kg Mg/ha. These amounts could be removed from the soil. However, when cassava was intercropped with leguminous crops and the residues incorporated into the soil, the amount of 49-80 kg N, 34-57 kg P_2O_5, 12-18 kg K_2O, 24-39 kg Ca and 9-15 kg Mg/ha were returned to the soil.

Those nutrients are equivalent to 100-200 kg urea, 300-500 kg fused magnesium phosphate and 20-30 kg KCl. So, intercropping legumes is considered as a good technology for soil conservation, especially for uplands. This technique has multiple benefits, such as higher income, increase in organic matter, and mineral nutrients returned to the soil.

2.3. The Effect of Green Manure Crops on Run-off and Erosion

Cassava cultivation without fertilizer inputs is a common practice of farmers. Moreover, few farmers use any soil conservation practices. This study focused on the effect of various contour hedgerows on soil erosion. Some results of the study are presented in **Table 15**.

Table 15. Effect of various cassava management practices on run-off and soil losses by erosion from an Acrisol at Tam Dao, Vinh Phu (slope 5-7^o) in 1994.

	Run off		Soil loss	
Management treatment[1)]	m^3/ha/year	%	t/ha/year	%
1. Bare land (control)	14,539	100	6.9	100
2. Cassava monoculture; low input	12,678	87	6.9	100
3. C+P; *Tephrosia* hedgerows; low input	12,433	84	6.1	88
4. C+P; *Tephr.* + pineapple hedgerows; low input	12,031	82	4.8	70
5. C+P; *Tephr.* + pineapple hedgerows; high input	11,473	79	2.8	41
6. C+P; *Tephrosia candida*+eucalyptus; high input	10,674	73	3.7	74

[1)] C = cassava; P = peanut

Source: Huynh Duc Nhan et al., 1995.

Data in **Table 15** show that intercropping with peanut and contour hedgerows of green manure crops such as *Tephrosia candida* markedly reduced soil erosion on sloping land. On bare land, water run-off and soil loss were most serious. In the cassava monoculture system, water run-off decreased by 13% compared with bare land. When cassava was intercropped with peanut (T3), run-off decreased to 84% of that from bare land and was 3% lower than that in the monoculture cassava system.

Cultivations of cassava intercropped with peanut and planting hedgerows of green manure crops further reduced run-off and soil loss. Using both a green manure crop and pineapple as a hedgerow, and intercropping, soil loss was only 41-70% of that in the monoculture cassava treatment. In addition, both soil loss and run-off were reduced by increasing the fertilizer inputs.

In treatments (T5, T6) with high inputs, soils losses were 2.8-3.7 t/ha/year, but it was 4.8 t/ha/year in treatment with low input (T4). Research on the degraded Acrisol derived from liparte rock in Tam Dao indicates that the nutrient balance was negative in the monoculture cassava system. They were estimated to be around 7.8 kg N, 8.9 kg P_2O_5, and

8.7 kg K_2O/ha/year. With intercropping and the planting of hedgerows, soil loss and run off were reduced, so that the nutrient loss was also reduced. In addition, green manure and crop residues (peanut) were returned to the soil, so nutrients in the residues were also returned to the soil. The amount of added nutrients was estimated at 55-67 kg N, 12-15 kg P_2O_5, 32-40 kg K_2O/ha. (**Table 16**). Intercropping and hedgerow planting also effected crop yields (**Table 17**). Monoculture cassava produced 10.8 t/ha fresh roots. Intercropping resulted in 7-9 t/ha fresh roots and 450-500 kg/ha/year of peanut pods.

Table 16. The effect of various cassava crop management treatments on the nutrients lost and returned to the soil (kg/ha) in Tam Dao, Vinh Phu, north Vietnam in 1994.

	N			P_2O_5			K_2O		
Treatments[1)]	M[2)]	RT[2)]	Balance	RM	RT	Balance	RM	RT	Balance
T_1	7.8	0	-7.8	8.9	0	-8.9	8.7	0	-8.7
T_2	7.6	0	-7.6	13.1	0	-13.1	7.5	0	-7.5
T_3	6.7	66.2	+59.5	12.8	13.6	13.1	8.8	36.5	+27.7
T_4	8.1	55.3	+47.2	11.0	12.2	+1.2	9.1	31.9	+22.8
T_5	4.5	67.2	+62.7	10.1	14.5	+1.2	7.1	40.1	+33.0
T_6	6.7	60.3	+53.6	9.9	14.5	+4.6	8.0	38.2	+80.2

[1)] Treatments: see Table 15.
[2)] RM: removal, RT: returned to the soil
Source: *Huynh Duc Nhan et al., 1995.*

Table 17. Effect of intercropping and hedgerows on cassava and peanut yields at Tam Dao, Vinh Phu, north Vietnam in 1994.

	Cassava root yield		Peanut pod yield	
Treatments	(t/ha)	(%)	(kg/ha)	(%)
2. Cassava monoculture; low input	10.8	100	0	0
3. C+P; *Tephrosia* hedgerows; low input	9.1	84	498.3	100
4. C+P; *Tephr.* + pineapple hedgerows; low input	7.6	71	450.4	90
5. C+P; *Tephr.* + pineapple hedgerows; high input	7.9	73	465.8	93
6. C+P; *Acacia candida*+eucalyptus; high input	6.9	64	479.2	96

Source: *Huynh Duc Nhan et al., 1995.*

2.4. Soil Management Practices to Maintain or Improve Soil Productivity.

To maintain or improve the productivity of soils used for cassava cultivation, it is necessary to reduce nutrient losses by crop removal and erosion, and prevent physical deterioration through excessive land preparation (especially with heavy machinery), and loss of clay and organic matter through erosion. In addition, the nutrients and organic matter lost should be replaced by application of fertilizers or manures, or by incorporation of green manures or intercrop residues.

2.4.1. Organic manures

Especially in the Red River Delta and in the northern part of the Central Coast, farmers are accustomed to applying 4-10 t/ha of manure, mostly pig or buffalo manure, to cassava. Results from the cassava survey conducted in Vietnam in 1990/91 (Pham Van Bien *et al.,* 1996) indicate that for the whole of Vietnam these manures may account for about 65% of N and K and 92% of all P applied to cassava. Manures are thus a major and indispensable source of nutrients for cassava, while also contributing organic matter and improving the physical conditions of the soil. These manure applications are particularly important when farmers remove all plant parts from the field, as they help restore soil organic matter and supply secondary and micronutrients. Still, **Table 18** indicates that the farmers' practice of high applications of FYM without N, P and K as chemical fertilizers did not result in maximum yields or profits. Highest yields and net income are probably obtained with modest (5-6 t/ha) applications of manure combined with about 60 kg N and 120 K_2O/ha, either without or with 30-60 kg P_2O_5/ha. Applications of Mg as fused Mg-phosphate are probably necessary in case no FYM is applied at all.

Table 18. Average results of five FPR fertilizer trials conducted by farmers in Kieu Tung village of Thanh Ba district, Phu Tho province, north Vietnam in 1996.

Treatment	Yield cassava (t/ha)	Gross income[1)]	Fertilizer costs[1)]	Net income
		(mil. dong/ha)		
1. 10 t/ha of FYM	15.93	7.96	1.00	6.96
2. 10 t/ha of FYM; 60N + 60P_2O_5 + 120K_2O	19.34	9.67	2.19	7.48
3. 10 t/ha of FYM; 60N + 60P_2O_5 + 80K_2O	18.67	9.33	2.05	7.28
4. 10 t/ha of FYM; 60N + 40P_2O_5 + 120K_2O	21.89	10.94	2.07	8.87

[1)] Prices: cassava fresh roots: d 500/kg; FYM: 100/kg; Urea (45% N): 3000/kg; SSP (17% P_2O_5): 1000/kg; KCl (60% K_2O): 2200/kg

Source: *Thai Phien et al., 1997.*

2.4.2. Green manures and alley/intercropping

Few experiments have been conducted in Vietnam to determine the effectiveness of planting and then incorporating a crop of green manure before planting cassava. In north Vietnam where farm size is small, few farmers will want to plant a non-productive crop for the sole purpose of improving soil fertility. However, in remote areas where land is abundant but fertilizers or manures are not available, this may be an attractive option. Moreover, the green manure may help to smother out *Imperata cylindrica* grass.

Alley cropping cassava with contour hedgerows of *Tephrosia candida* is a well-established practice in some parts of north and central Vietnam. It is used to control erosion as well as to improve soil fertility when the prunings of the hedgerows are mulched or incorporated. Thai Phien *et al.* (1995) reported that *Tephrosia* hedgerows produced on average 0.5-1.0 t/ha/year of dry biomass for incorporation into the soil, which may contribute 10-20 kg N/ha. This compares with 1.5-2.0 t/ha of dry residues of intercropped black bean supplying 35-40 kg N/ha, or 4-5 t/ha of dry residues of intercropped peanut supplying 50-70 kg N/ha. Only part of this N is added to the system through biological N fixation by the legumes.

Trials conducted for four years in Hung Loc Center in Dong Nai, south Vietnam, indicate that intercropping cassava with grain legumes, such as mungbean, soybean, cowpea, peanut, winged bean (*Psophocarpus tetragonolobus*) and sword bean (*Canavalia ensiformis*) decreased cassava yields about 10-20%, and that planting cassava in single rows at 1.0x1.0 m produced higher yields than planting in double rows. Intercropping with maize also reduced cassava yields about 20-25%. Profits were highest for cassava monoculture or intercropped with peanut (Nguyen Huu Hy *et al*., 1995).

Numerous erosion control trials conducted in both north and south Vietnam have shown that run-off and erosion losses can be markedly reduced by intercropping and by planting of contour hedgerows. Intercropping with peanut was generally more effective in reducing erosion than intercropping with other crops (**Table 19**), due to the rapid formation of soil cover. Contour ridging and no- or reduced-tillage were effective in reducing erosion, while adequate fertilization also helped to reduce erosion (Nguyen The Dang *et al*., 1998). However, contour ridging, fertilization and intercropping require more work and usually imply higher production costs. Hedgerows also require more work in establishment and maintenance and may reduce yields by occupying 10-20% of the land. Thus, farmers have to consider the trade-off between immediate costs and benefits *versus* long-term benefits of less erosion and improved fertility.

Table 19. Effect of intercropping cassava with various grain legumes on the yield of crops, on gross and net income, as well as on dry soil loss due to erosion when grown on 10% slope at Agro-forestry College of Thai Nguyen University, Thai Nguyen, Vietnam in 1997.

Intercropping treatments	Yield (t/ha)		Gross income[1)]	Costs fert. seed[1)]	Net income	Dry soil loss
	Cassava	Intercrop	———	(mil. d/ha)	———	(t/ha)
1. Cassava monoculture	18.67	-	7.47	6.22	1.25	31.24
2. C + peanut	16.50	1.08	12.00	8.77	3.23	24.03
3. C + soybean	18.42	0.15	8.27	7.98	0.29	28.50
4. C + mung bean	20.83	0.27	10.49	7.84	2.65	28.61
5. C + black bean	17.92	0.35	9.62	7.94	1.68	28.64
6. C + cuoc bean	17.67	0.17	7.92	7.87	0.05	28.14

1) Prices:	cassava:	400d/kg fresh roots		
	peanut:	5000d/kg dry pods	peanut seeds:	7000d/kg dry pods
	soybean:	6000d/kg dry grain	soybean seeds:	7000d/kg dry grain
	mungbean:	8000d/kg dry grain	mungbean seeds:	8000d/kg dry grain
	black bean:	7000d/kg dry grain	black bean seeds:	7000d/kg dry grain
	cuoc bean:	5000d/kg dry grain	cuoc bean seeds:	5000d/kg dry grain

Source: *Le Sy Loi, 2000.*

Intercropping and planting hedgerows of *Tephrosia candida* to conserve soil fertility had other benefits. They reduced soil and nutrients lost by erosion (**Table 20**). Under monoculture cassava, 22.88 t/ha of dry soil were lost, while intercropping with peanut, planting hedgerows of *Tephrosia candida*, and applying NPK fertilizers soil loss was only 0.22 to 3.21 t/ha. This treatment also markebly reduced nutrient losses by erosion.

Intercropping cassava with peanut and planting hedgerows can also return large amounts of green matter and nutrients for soil fertility conservation. **Table 21** shows the amounts of green matter and nutrients returned to the soil. These were generated from two components: hedgerow prunings and peanut residues.

Table 20. Affect of intercropping, hedgerows and fertilizer application on soil and nutrients lost by erosion in Dong Rang commune, Luong district, Hoa Binh province. 1995-1997.

Treatments[1)]	Soil loss (t/ha)	Nutrient loss (kg/ha/year)				
		N	P	K	Ca	Mg
1. C	22.88	45.8	39.90	6.80	4.6	4.4
2. C + P + H + NPK	0.22	0.4	0.39	0.08	0.5	0.5
3. C + P + H + NP	2.56	5.3	4.60	0.83	0.6	0.5
4. C + P + H + NK	0.22	0.4	0.39	0.08	0.5	0.1
5. C + P + H + PK	3.21	6.7	5.60	0.66	0.6	0.7

[1)] C = cassava; P = peanut; H = hedgerows of *Tephrosia candida;* NPK = 40 kg N + 40 P_2O_5 + 80 K_2O/ha; peanuts received separately 7 kg N + 20 P_2O_5 + 20 K_2O/ha

Source: *Le Thi Dung and Thai Phien, 1998.*

Table 21. Effect of intercropping, hedgerows and fertilizer application on organic matter and nutrients returned to the soil in Dong Rang commune, Luong district, Hoa Binh province. 1995-1997.

Treatments[1)]	Organic matter (kg/ha/year) from		Nutrients returned to soil (kg/ha/year)				
	Hedgerows	Intercropping	N	P	K	Ca	Mg
1. C	0	0	0	0	0	0	0
2. C + P + H + NPK	864	1276	50.3	7.9	38.0	21.6	23.1
3. C + P + H + NP	864	1296	50.7	8.0	38.5	21.8	23.4
4. C + P + H + NK	864	1354	51.8	8.1	39.6	22.4	24.1
5. C + P + H + PK	864	1351	51.9	8.1	39.7	22.5	24.1

[1)] Treatments: see Table 20.

CONCLUSIONS

Research conducted on experiment stations, on farmers' fields and with direct participation with farmers have shown that:

1. Cultivation of cassava on slopes may cause more severe erosion than that of other annual crops due to cassava's wide plant spacing and slow initial growth. But, it may cause less erosion than short-cycle crops (vegetables, beans) that are planted 2-3 times per year, and which require frequent land preparation and weeding.
2. Nutrient removal in eroded soil and run-off water can be substantial, especially K in run-off and sediments, and N in sediments, but nutrient losses from erosion are generally lower than those due to crop removal.
3. Soil nutrient depletion and exhaustion can be prevented by application of adequate amounts of chemical fertilizers, organic manures or compost; or by incorporation of cassava plant tops, green manures, intercrop residues or prunings of hedgerows.
4. Farm-yard manure (FYM) is an essential source of nutrients to improve soil fertility and increase growth and yields of crops grown in upland areas. Application of FYM can increase available P, exchangeable K, mineralizable N and soil organic matter.
5. Intercropping cassava with grain legumes and returning their residues to the soil is a profitable technology which also improves soil fertility. Planting contour

hedgerows of green manure crops can significantly reduce soil losses and run-off on sloping lands.

6. The nutrient balance in the soil under cassava cropping is normally negative, especially with respect to K. Returning the residues of intercropped grain legumes could alleviate this problem. A combination of FYM, inorganic fertilizers, and incorporation of residues of leguminous crops often increases yields significantly. This is an adoptable technology. Farmers have successfully participated in research and the transfer of this technology to other farmers in the community.
7. From the research it was estimated that cassava took up 99-153 kg N, 57-113 kg P_2O_5, 38-56 kg K_2O, 50-81 kg Ca and 19-32 kg Mg/ha. These amounts could be removed from the soil. Where cassava was intercropped with leguminous crops and the crop residues were returned, about 49-80 kg N, 34-57 kg P_2O_5, 12-18 kg K_2O, 24-39 kg Ca and 9-15 kg Mg/ha could be returned to the soil.
8. Alley cropping cassava with contour hedgerows of *Tephrosia candida* is a well-established practice in some parts of north and central Vietnam. *Tephrosia* hedgerows produced an average of 0.5-1.0 t/ha/year of dry biomass for incorporation into the soil. This may contribute 10-20 kg N/ha. In intercropping systems, black bean could supply about 1.5-2.0 t/ha of dry residues, containing 35-40 kg N/ha, or peanut could supply about 4-5 t/ha of dry residues with 50-70 kg N/ha. By intercropping the grain legumes with cassava and returning the residues, in three years the soil OM was increased by 0.22% in the surface and 0.19% in the subsoil as compared to the control treatment. Returning the bean residues and applying FYM increased the soil OM and N; soil OM was increased 0.28-0.61% in the surface soil and 0.25-0.82% in the subsoil. Planting *Tephrosia candida* as contour hedgerows and returning pruned leaves and stems to the soil, soil OM was increased 0.3-0.4%, compared to the previous two years.
9. Soil organic matter plays an essential role in soil fertility. Soil OM management by the use of FYM, green manures, intercropping and green hedgerows, and returning crop residues to the soil, is a technology widely applied by farmers for achieving sustainable agriculture in Vietnam.

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